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Cephalometric imaging in the assessment of facial growth direction; literature review

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Summary

The aim of this study was to present methods of assessment of facial growth on cephalometric imaging described in the literature.

In the study articles published in foreign journals assessments of facial growth were described. PubMed, Medline and Ebsco bases have been used for finding appropriate literature. Key words like: cephalometry, superimposition methods, craniofacial growth were used for searching. We chose 31 articles which described this problem.

Craniofacial growth and development is an important problem in orthodontic diagnosis and treatment. It may be a support but also an obstacle to the orthodontic therapy; it can even make it impossible. In order to define it on cephalometric imaging it is necessary to assess: craniofacial development on reference landmarks of the cranium base; maxillary growth- in relation to points based on maxilla and development of mandible alveolar process- superimposition of images on the structures localized in mandible. Different methods of superimposition described in the study allow assessing, more or less precisely, the direction and dimension of growth in time between one imaging and another.

Key words: cephalometry • superimposition methods • craniofacial growth

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Background

Growth and craniofacial development is an extremely important factor in orthodontic treatment of children and youth. It may be a support but also an obstacle to the therapy, in extreme cases it may even make the treatment impossible [1]. The following aspects of growth assessment are taken into account: its expected direction, intensity and duration. The duration and intensity may be determined with a high degree of precision but direction is rather difficult to predict and it should be done very carefully. Cephalometry became an essential tool in the investigations of facial growth direction. Knowledge of a normal facial growth makes it possible to prepare a correct treatment plan, ensuring its successful implementation and stable results in young patients. The aim of this study was to describe different methods in the assessment of facial growth direction on cephalometric imaging based on the literature.

In 1931, two scientists - Hofrat in Germany and Broadbent in the US - independently generated lateral teleradiographs of the skull. It enabled them to include in a single picture majority of structures important for orthodontics. A cephalometric image (cephalograph, kephalograph or lateral teleradiograph of the skull) shows not only the bony structure but also soft tissue profile [2]. The term cephalometry originates from two Latin words: "kephale" means "head" and "metrein" - "to measure", and it signifies measurement of the extraoral and intraoral head structures. Cephalographs have become a diagnostic tool in orthodontics as they allow successful measurements which previously seemed to be insufficient or even impossible to proceed. A cephalometric image undergoes significant changes along with the growth of the examined person [2]. Observation of teleradiograph allows assessing the facial skeleton, but there is also a necessity to prepare an objective data which is a base to numerous cephalometric analyses.

In 1930, Hellman as the first researcher established biological standards of human development. He presented the standards in form of profile diagrams measured from the auriculare (Au) landmark to the landmarks: Nasion (N), prosthion (Pr), infradentale (Id), gnathion (Gn), and gonion (Go) (Fig. 1) [3].

Another long-term study was carried out by Broadbent [2]. His method was to make four teleradiographs documenting consecutive growth stages of a single patient. Afterwards he superimposed them along the Nasion-Bolton line. He also determined an additional reference point - R, located perpendicularly midway from the centre of the sella turcica to the Nasion-Bolton line. He superimposed the images on the R point and the Nasion-Bolton lines were parallel (Fig. 2) [2, 4].

Assessment of the skeletofacial development

With his studies, Broadbent initiated the development of assessment methods for the growth- and treatment-related changes in spatial skeletofacial structures. The method was based on superimposition of cephalographs made in several time intervals. In orthodontics, image superimposition technique is performed in order to evaluate three basic variables affecting the development of the maxillary alveolar processes and the mandible and assessing overall changes in skeletofacial structures. For that purpose, it is necessary to superimpose the pictures based on relatively stable landmarks on the skull surface, within the maxilla and mandible. It allows observation of spatial changes in bone structures resulting from the growth process and treatment [5].

Stability of reference points is necessary to perform of a detailed diagnosis [6, 7,8,9,10,11]. Changes in the facial skeleton should be observed in reference to landmarks located in outer structures, such as the cranial base [12]. Unlike facial skeleton, the cerebral cranium grows fastest in early period of human life and it reaches 90% of its final size at the age of 4-5 [4]. Therefore, it may be assumed that landmarks localized on its basis meet the requirements of the superimposition method. In another research it was found that the cranial growth is first complete in the area of anterior cranial fossa [13], particularly between the pituitary fossa and foramen caecum where the bony structures reach 98% of their final size in children aged 8-13. The posterior part of cranial base grows at an early stage of life as a result of activity of the spheno-occipital suture; however, growth of its anterior segment is a consequence of development of frontal sinuses, which causes migration of the Nasion landmark (N) [13, 14, 15].

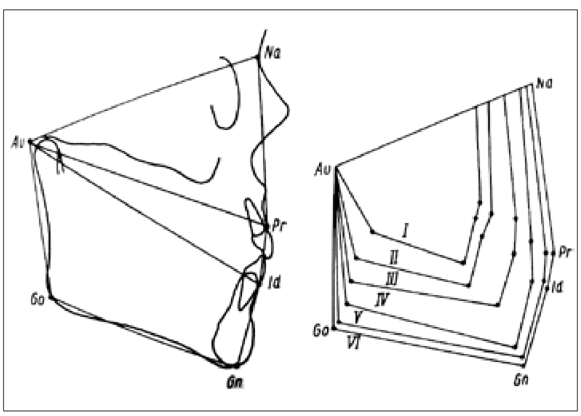

Figure 1. Hellman's diagrams according to Weinberger [3].

In literature there are many descriptions of cephalometric image superimposition methods concerning the cranial base. The first was based on the above-mentioned studies conducted by Broadbent in 1931. In 1953, DeCoster developed a method of superimposing images along the cribriform plate and the sphenoid bone as they become stable at the age of 7 [13, 15].

The superimposition method was used for studying the facial growth direction but the landmarks varied [12, 15, 16, 17]. Today, authors [4, 5, 10, 18] use cranial base as a reference line and apply the below-mentioned research methods.

1. Superimposition on the reference points R provided that the Nasion-Bolton lines remain parallel – as described by Broadbent.

2. Superimposition along the Sella-Nasion line is one of the most frequently used methods owing to the fact that the line is considered to be the most stable (Fig. 3) [1, 12, 19].

In his study of the cranial growth, Steiner used the SN line together with the S reference landmark, in order to show sagittal changes of the mandible, and with the N reference point - with respect to the maxilla [18].

In course of examination carried out by Björk, the S point was used for determining changes in both, the upper and lower jaw positions [15]. Later on, the author observed that displacement of the Nasion landmark accompanied growth

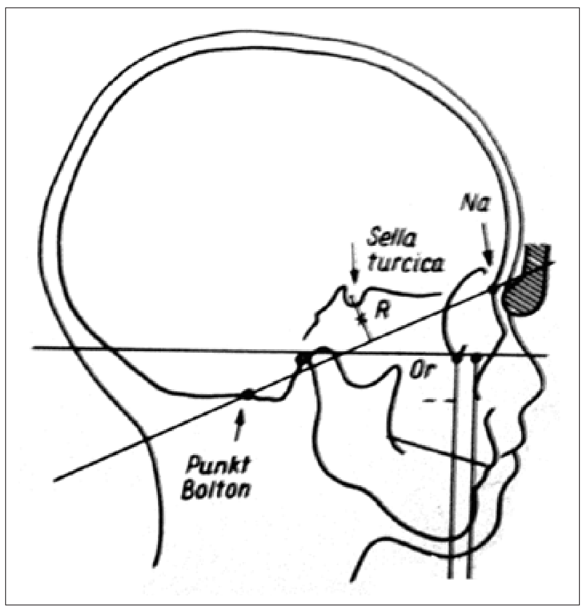

Figure 2. Superimposition on R point and along the Nasion-Bolton lines according to Broadbent [2].

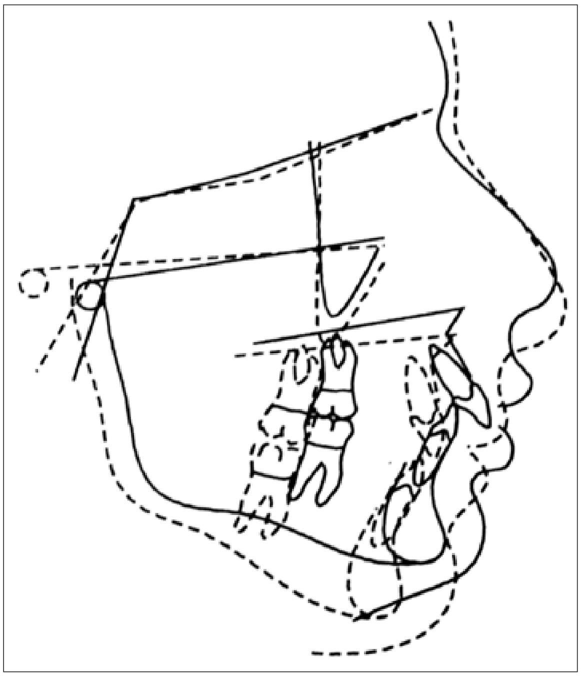

Figure 3. Superimposition along the SN line [19].

of the nasofrontal suture and movement of the Sella point which resulted from the sella turcica's transformation caused by growth of the pituitary gland.

3. The best-fit method consists in the superimposition of cephalographs of as many points as possible, including: anterior wall of the sella turcica, anterior border of the middle cranial fossa, cribriform plate, crista galli and frontal crests, as well as cerebral surface of the roof of the orbit and interior cortical plate of the frontal bone [15]. Reliability of that method is confirmed by the research conducted by Sakima et al. [9] which proved stability of the interior surface of the frontal bone and cribriform plate in children older than 6 or 7 y.o. (Fig. 4).

4. Superimposition along the Basion-Nasion lines according to the method developed by Ricketts [17]. The author of that growth-assessment technique also used two landmarks: the CC construction point at the intersection of the Ba-N and Pt-Gn lines (the Pt point is located at the lower edge of the circular foramen and it is the highest and most posterior point on the outline of the pterygopalatine fossa), and the N point. The angle between the Ba-N and Pt-Gn lines reflects the position of mandible with respect to maxilla. By using the N point as the central, it is possible to determine a change in position of the maxilla which results from the A point displacement (Fig. 5). According to the Ricketts' method, superimposition of the CC point is referred to as position I and of the N point – as position II. He also developed positions III and IV to be discussed below.

Pancherz [12] suggested a method of modified superimposition of images along the SN line, where the reference landmark is S point. The author used occlusion line (OL-line) with a perpendicular line OLp intersecting the

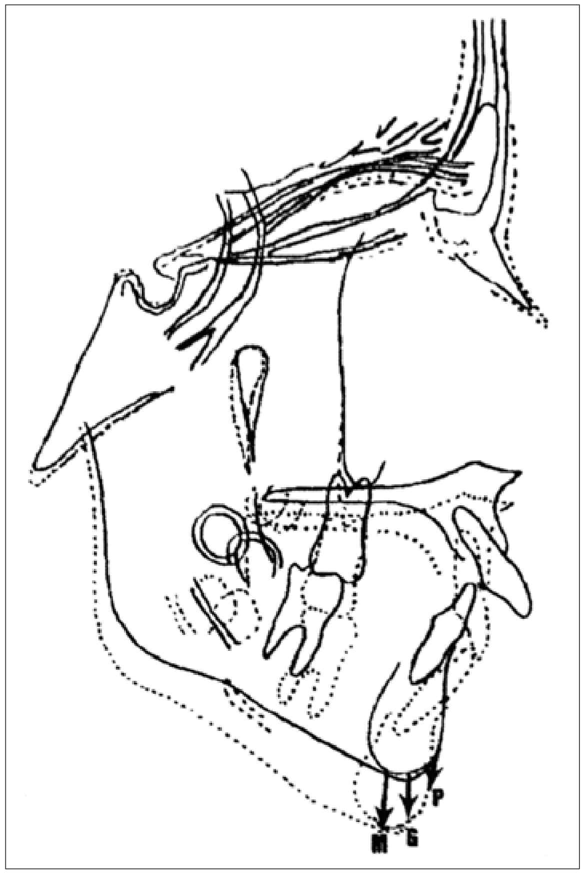

Figure 4. The best-fit method [15].

point S. Superimposition of two images along the SN line and at the S point makes possible to assess both the changes along the occlusion plane (OL) and the distance from OLp. This method includes the examination of positions of the U6, L6, U1, L1, A, B, and Pg points (Fig. 6).

Maxillary growth assessment

Superimposition of cephalographs based on the cranium allows assessment of changes in the position of the maxilla and the mandible in relation to it. To evaluate changes in tooth structures within the maxilla and mandible it is necessary to superimpose images of those bones.

Superimposition of the maxillary structures is performed to analyze transformations of the alveolar processes during the growth period and result from orthodontic treatment [21]. Björk in his investigation (1955) placed tantalum implants in the maxilla and mandible, which enabled him to carry out detailed, superimposition-based research and explain dynamic, growth-related changes. He placed the implants in three anatomical regions of the maxilla, namely: anterior implant – below the anterior nasal spine (ANS), lateral one – in the zygomatic process of the maxilla and the third one at the junction of hard palate and alveolar process of the maxilla in the mesial direction compared to the first molar. The implant-based research executed by Björk and Skieller (1957) revealed that the anterior surface of the zygomatic

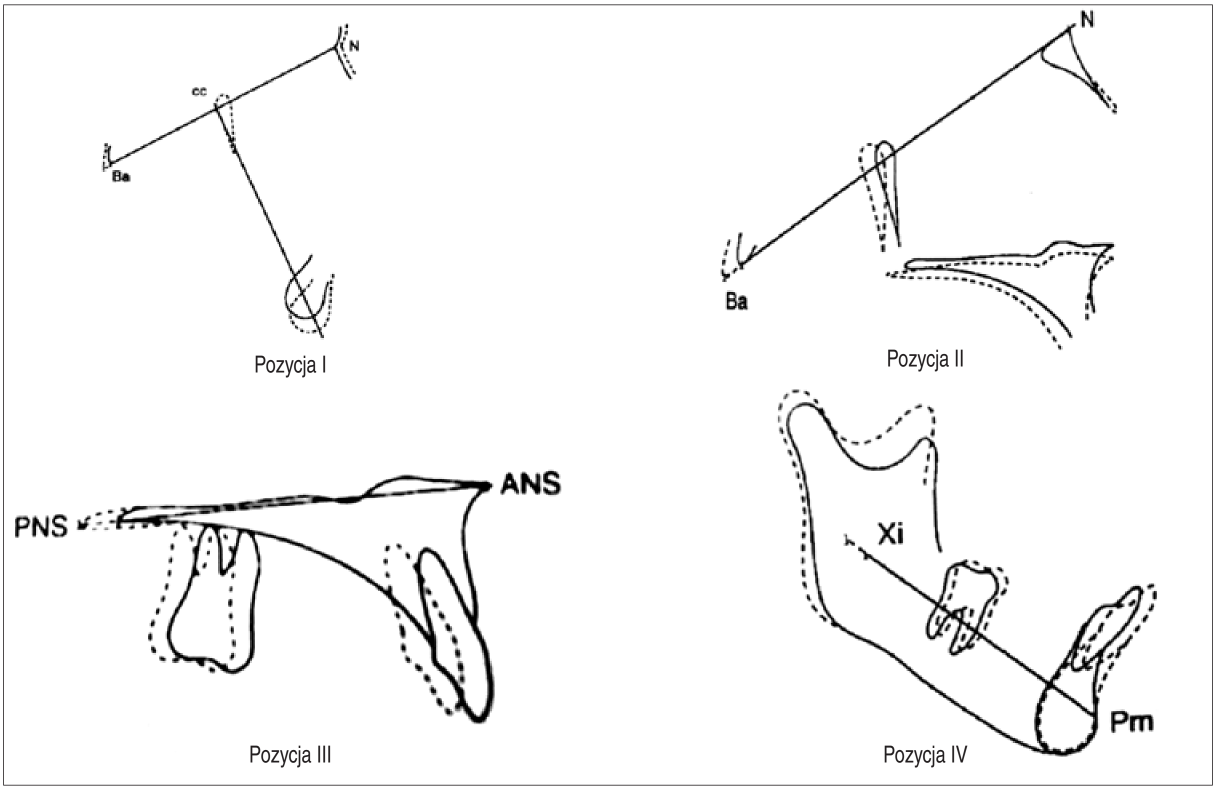

Figure 5. Four positions of cephalometric image superimposition according to Ricketts [17].

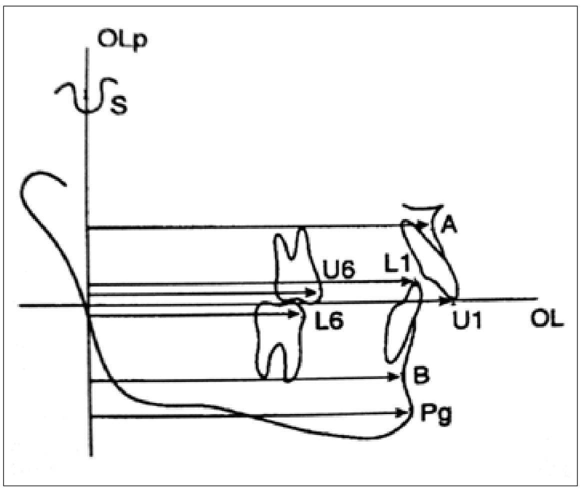

Figure 6. Pancherz's method of superimposition of cephalographs [12].

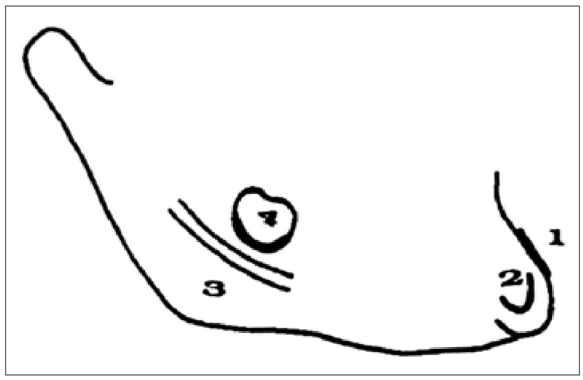

Figure 7. Björk's structures (reference landmarks in the mandible) [21].

process is stable in the sagittal dimension, what allows superimposition of images of the maxilla in that area.

The most popular maxillary structures' superimposition technique is to use the plane of the hard palate as a reference line. It leads through the ANS, PNS and PTM (pterygomaxillary fissure) landmarks. This technique was used by Ricketts, with regard to his position III (Fig. 5), and by Nielsen [22] who found that it was impossible to specify any stable reference points within the maxilla that would always allow an unquestionable analysis of changes within the alveolar processes and teeth as compared to the implant-based superimposition method.

Mandibular growth assessment

To evaluate changes induced by growth or treatment in the area of alveolar processes and teeth of the mandible, the superimposition method based on relatively stable reference landmarks is also possible. The points on the abovementioned research carried out by Björk using implants. The landmarks are referred to as Björk's structures [21] and they include: the highest anterior border of the mentum-1, internal cortical surface of the mandibular symphysis-2, mandibular canal-3 and lower outline of the third molar bud (before root mineralization)-4 (Fig. 7). Björk's structures were recognized by the British Orthodontic Society as recommended for the mandibular superimposition method.

Another method of mandibular superimposition is position IV suggested by Ricketts. It is based on a reference

Table 1. Abbreviations used in work of reference points on the cranium that are used during cephalometric analysis; localization description.

N/Na	Nasion	The most anterior point of nasofrontal suture in mid-sagittal plane
Pr	Prosthion	The lowest and most anterior point on the alveolar border of the maxilla between the central incisors
Id	Infradentale	The most superior and most anterior point of alveolar part of mandible located in mid-sagittal plane, between lower central incisors
Gn	Gnathion	Point between the most anterior and inferior point of chin
Go	Gonion	Point where inferior margin of the mandibular corpus and the posterior margin of the ramus meet
B/Bo	Bolton	The most superior point of upper curve of retrocondylar fossa of occipital bone
Ba	Basion	Point located most inferiorly on the inner border of the anterior margin of the foramen magnum
S	Sella	Roentgen point in medial plane, formed in place where perpendicular lines running from the centre of pituitary sella meet
ANS	Anterior nasale spina	The most anterior point of anterior nasal spine in mid-sagittal plane
PNS	Posterior nasale spina	Roentgen point formed where the lines of anterior wall of and base of nasal spine meet pterygopalatine fossa
PTM	Pterygomaxillary fissure	View of palatine plane, anterior wall of maxillary fissure, posterior wall of anterior curve of pterygoid, equals PNS
Pm	Protuberance menti	The most superior point of chin line
Pt		Point on inferior margin of round foramen at the same time beeing a point located most anteriorly and superiorly within pterygopalatine fossa
U6	Upper molar tip	Mesial nodule of the 1st upper molar tooth
L6	Lower molar tip	Mesial nodule of the 1st lower molar tooth
U1	Upper incisor tip	Incisor tip of the most anterior upper incisor
L1	Lower incisor tip	Incisor tip of the most anterior lower incisor
A	Subspinale	The deepest point on concave contour of bone from mandible base to tooth
B	Supramentale	The deepest point of anterior contour of dental part of mandible in mid-sagittal plane
Pog	Pogonion	The most anterior point on bone outline of chin
Xi		Geometrical middle of mandible ramus (point where diagonal lines of the biggest rectangle on the mandible ramus meet)
CC		Construction point where Ba-N and Pt-Gn lines cross
R		Construction point located midway between the centre of sella (S) and perpendicular to nasion-Bolton(N-B) line

line joining the Pm landmark (protuberantio menti) and the Xi construction point located in the centre of the mandible.

A comprehensive spatial changes' assessment procedure should consist of: 1) superimposition of cephalographs on the reference landmarks of the cranium base according to one of the above-mentioned methods of showing changes in the facial skeleton, 2) superimposition of images on the maxilla allowing to evaluate changes in the position of the alveolar process of the maxilla, and 3) superimposition on the area of the mandible allowing evaluation of development of the alveolar process of the mandible [23]. Nevertheless, those three steps provide no final answer as regards the change in position of the mandible with respect to the maxilla. Efstratiadis and Ghafari proved that there were differences in vertical and, to a smaller degree, in horizontal displacement of the menton, gnathion and pogonion landmarks, depending on whether the images were superimposed on the cranium base points or on mandibular landmarks [24].

The image superimposition methods presented in this paper allow a more or less precise assessment of growth direction and rate in the time that elapsed between the dates the examinations. They also show further trends which are particularly important for evaluations concerning the mandible. Additionally to the superimposition method, also a structural method is used to assess mandibular growth tendencies. It is based on the assumption that intensity of certain morphological features in the mandible reflects its growth direction. The method was developed by Björk, who separated seven features which make it possible to evaluate the predicted rotation and growth direction of the mandible. For this purpose it is necessary to analyze:

– degree and direction of the mandibular head inclination,

– shape of the mandibular canal,

– shape of the lower border of the body of the mandible,

– shape of mental protuberance,

– interincisial angle,

– anterior facial height index,

– size of mandibular angle [25, 26, 27].

Cephalometric measurments are based on mathematical calculations but it should be remembered that they refer to structures ruled by biological laws. In consequence, conclusions should be drawn carefully from their results. The method of superimposition of cephalographs constitutes a valuable supplement to radiographic diagnosing in orthodontics as it increases the reliability of forecasts. Methods of the assessment of facial growth direction on cephalometric imaging described in the literature are necessary for planning the treatment of patients with active growth potential. Further investigations on accuracy of these methods and their actual utility in the orthodontic diagnosis need to be carried out.

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